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COVID-19 pandemic repercussions on plastic and antiviral polymeric textile causing pollution on beaches and coasts of South America

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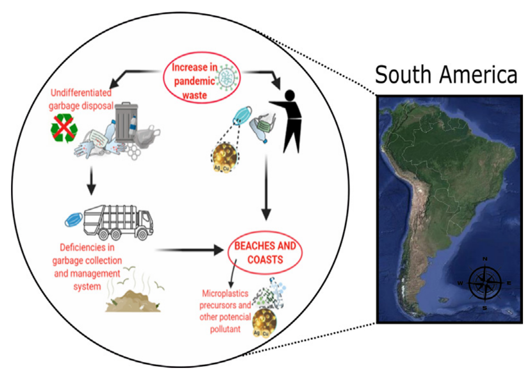
HIGHLIGHTS

- The unprecedented increase in face mask production is a current global environmental concern caused by the COVID-19 pandemic.
- The plastic waste from single use face masks is hazardous for marine species.
- Textile fibers impregnated with Ag and Cu nanoparticles could have long-term adverse effects on aquatic environments.
- Deficiencies in Solid Waste Management in South America were accentuated during COVID-19.
- Recommendations were suggested to improve waste management practices in South American countries.

GRAPHICAL ABSTRACT



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ABSTRACT

The propagation of the COVID-19 pandemic worldwide has been alarming in the last months. According to recommendations of the World Health Organization (WHO), the use of face masks is essential for slowing down the transmission rate of COVID-19 in human beings. This pandemic has generated a substantial increase in the use, as well as in the production, of face masks and other elements (gloves, face protectors, protective suits, safety shoes) manufactured with polymeric materials, including antiviral textiles most of which will end as microplastic pools. Focusing on South America, the use and mismanagement of this type of personal protective equipment (PPE) represents an environmental problem. Added to this issue are the increase in the use of single-use plastic, and the reduction of plastic recycling due to the curfew generated by the pandemic, further aggravating plastic pollution on coasts and beaches. Recently, researchers have developed antiviral polymeric textile technology composed of Ag and Cu nanoparticles for PPE to reduce the contagion and spread of COVID-19. Antiviral polymeric textile wastes could also have long-term negative repercussions on aquatic environments, as they are an important emerging class of contaminants. For this reason, this work provides reflections and perspectives on how the COVID-19 pandemic can aggravate plastic pollution on beaches and coastal environments, consequently increasing the damage to marine species in the coming years. In addition, the potential impact of the pandemic on waste management systems is discussed here, as well as future research directions to improve integrated coastal management strategies.

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1. Introduction

Plastic is one of the synthetic or semisynthetic materials that have revolutionized the twentieth century. It has several advantages over traditional materials in many application areas due to its versatility, resilience, abundance, transparency, lightness, and low cost, among others (Shrivastava, 2018). According to the intrinsic or extrinsic properties of plastic materials, they can provide a package of customized solutions to a wide variety of daily life necessities. In 2018, plastic production reached 359 million metric tons worldwide, of which Asia was the leading producer with 50.1%, followed by the USA 18%, Europe 17%, and Middle East-Africa 7%. Latin American countries, mainly Mexico, Brazil, Argentina, and Colombia, were responsible for 4% of the production and manufacturing of plastic products oriented to the packaging industry, specifically, in the processed products that are destined to rigid containers and films (Plastics Europe, 2019; Tecnología del Plástico, 2004).

Plastic materials have become a global pollution problem due to their no-biodegradability and ubiquity (Li et al., 2016; Yu et al., 2019). A large proportion of plastic waste comes into oceans from land-based sources. They can be transported by strong winds, rivers, storm drains, and tides or by direct discharges into the aquatic ecosystems (Moore, 2008; Li et al., 2016). In the environment, these materials present a high fragmentation into smaller plastic particle level due to erosion mechanics and weathering processes caused by strong tides, mechanical abrasion against rocks and sand, UV-light, and hydrolysis, among others, (Barnes et al., 2009; Wang et al., 2017; Paul-Pont et al., 2018). According to their size, these plastic particles are classified as meso, micro, and nanoplastics. Mesoplastics are small pieces between 5 and 25 mm while microplastics (MPs) are defined as plastic particles smaller than 5 mm caused by the degradation of large plastics (secondary MPs), or by release during manufacturing processes of commercial products (primary MPs) (Barnes et al., 2009; Thompson et al., 2009; Andrady, 2011; Wright et al., 2013; Paul-Pont et al., 2018). Finally, nanoplastics (PNPs) are defined as plastic colloidal particles (1 nm–1 μm). These PNPs present a Brownian motion in aqueous systems due to colloidal size range (Gigault et al., 2018). Moreover, all these plastic particles can also serve as a vector for other pollutants or be ingested by aquatic organisms in the food chain. Focusing on South America, production, excessive use, and poor waste management of these materials have generated plastic pollution on beaches, bays, coastal and aquatic environments (Andrade et al., 2018; Acosta-Coley et al., 2019a, 2019b; Fernandez Severini et al., 2019, 2020; Garcés-Ordóñez et al., 2019; Olivatto et al., 2019; De la Torre et al., 2020; Kutralam-Muniasamy et al., 2020; Martínez Silva and Nanny, 2020; Villagran et al., 2020).

According to a United Nations Environment Programme report (UNEP, 2018a, 2018b, 2018c), Latin America and the Caribbean generate 541,000 tons/day of waste, of which an average of 145,000 (including 17,000 of plastic waste) are burned or disposed of in open dumpsites (UNEP, 2018a; USAID, 2019). Likewise, a report of the World Bank (Kaza et al., 2018) under the title "A Global Snapshot of Solid Waste Management to 2050" informed that in 2016, Latin America and the Caribbean generated 231 million tons of waste. Moreover, this publication also detailed that according to each South American country's per capita income, there is a change in the composition of solid waste generated by these countries (Kaza et al., 2018). In particular, plastic waste represents 8% of the total solid waste from countries with a lower-middle per capita income (Bolivia, Guyana, and Paraguay), while 11% and 12% correspond to countries with an upper-middle (Colombia, Argentina, Brazil, Ecuador, Perú, and Venezuela) and a high per capita income (Chile and Uruguay), respectively (Kaza et al., 2018).

According to UNEP's projection (2018a) and USAID (2019), nowadays, the population is nearly over 440 million people. The COVID-19 pandemic impact on Latin America and the Caribbean nations has been alarming since it has spread to 19 countries in just two weeks (AS/COA, 2020). The SARS-CoV-2 virus is responsible for the first wave of this pandemic that reached the countries of South America later than North America and Europe. According to the Pan American Health Organization (PAHO), South America informs 8,200,000 confirmed cases and 259,300 deaths until October 5, 2020 (PAHO, 2020). To reduce the chances of being infected or spreading COVID-19, the World Health Organization (WHO) recommends the use of face masks, social distancing, hand washing, and disinfecting. These suggestions are all part of an essential method for slowing down the transmission rate of COVID-19 in human beings (WHO, 2020). In this way, almost all South American countries have established public policies of curfew and social distancing (Decree ASPO 297/2020; Decree 044/2020; Decree 457/2020; Decree 104/2020; Decree 4199/2020; Decree 1017/2020).

This pandemic has generated changes in human consumption patterns since these strict public policies have affected all socio-economic sectors, especially commerce, service, and tourism. One clear example is the substantial increase in the manufacturing and indiscriminate use of personal protective equipment (PPE) such as gloves, face protectors, medical face mask, protective suits, safety shoes, and N95 medical mask, as well as plastic containers for gels and alcohols (WHO/HWW, 2020) as well as cloth masks (Shruti et al., 2020). Likewise, excessive use of waste bags at home and single-use plastic (light-weight plastic bags, disposable utensils, beverage containers, single-use cold-drink cups, and food plastics containers) (Tenenbaum, 2020). Moreover, some nations' environmental standards have been lowered to accelerate their response to the pandemic, like in several North American states, where the ban on single-use bags and straws has been suspended (Silva et al., 2020a). Nevertheless, in South America, some countries have maintained these restrictions or even increased them. Chile, in particular, was the first in South America to ban the use of plastic bags throughout the national territory (August 3, 2020) during the pandemic (Law No. 21100, 2018), while in many other countries these restrictions are only at the municipal or provincial level. For example, in Colombia the Archipelago of San Andrés, Providencia and Santa Catalina and smaller islands prohibit the entry and use of plastic bags since 2019 (Law No. 1973/2019). In addition, a resolution on the prohibition of single-use plastics for the capital of this country, Bogotá D.C, came into effect in August 2020. However, this is not enough. As it can be seen, only a few countries or cities are involved in these positive issues in the context of the pandemic. In coastal cities, waste management is a crucial factor to prevent waste from reaching the sea, considering that the main source of coastal and marine garbage is terrestrial (Kane and Clare, 2019). Latin America and the Caribbean have a considerable extension of coasts where urban settlements have increased between 9 and 20% in a period from 1945 to 2014 (Barragán and de Andrés, 2016), which also means an increase in the pressure exerted on marine and coastal ecosystems, potentially compromising their health. One of the pressures is plastic litter generated in urban settlements, and consequently plastic contamination, which has become a worldwide threat exacerbated by the COVID-19 pandemic. In the medium-long term, this could lead to an increase in pollution by MPs.

A small number of researchers have reported MPs pollution on beaches, coasts, and rivers of South America before the COVID-19 pandemic. For example, the Caribbean coast and beaches of Colombia (Acosta-Coley and Olivero-Verbel, 2015; Acosta-Coley et al., 2019a, 2019b; Garcés-Ordóñez et al., 2019; Rangel-Buitrago et al., 2019a), and Magdalena River, Colombia (Martínez Silva and Nanny, 2020). Galápagos Islands (Van Sebille et al., 2019), and Guayllabamba River (Donoso and Rios-Touma, 2020), in Ecuador. The beaches, gulfs, and channels of southern Chile (Hinojosa and Thiel, 2009; Hidalgo-Ruz and Thiel, 2013; Rangel-Buitrago et al., 2019b), Perú-Chile coast (Perez-Venegas et al., 2020), and beaches in Perú (Purca and Henostroza, 2017; De la Torre et al., 2020; Lannacone et al., 2020). Río de la Plata, and Bahía Blanca estuaries (Acha et al., 2003; Pazos et al., 2017; Fernandez Severini et al., 2019; Forero López et al., 2020), Paraná River (Blettler et al., 2017, 2019), beaches of the Southwestern Atlantic, and coastal areas of Puerto Madryn city: (Becherucci et al., 2017; Ríos et al., 2020), in Argentina. Beaches of Punta del Este, and coast of Uruguay Atlantic, Uruguay (Lozoya et al., 2016; Rodríguez et al., 2020), and Pantanal wetlands, Paraguay (Faria et al., 2019). Beaches of Fernando Noronha island (Brazil) (Ivar et al., 2009), beaches and coastal (Turra et al., 2014; Moreira et al., 2016; De Carvalho and Baptista Neto, 2016; Neto et al., 2019a), estuaries and bays (Lima et al., 2015; Castro et al., 2016; Alves and Figueiredo, 2019; Olivatto et al., 2019; Neto et al., 2019b), in Brazil. In essence, the main findings showed that MPs levels are significant, and its distribution in the aquatic environment of this region is highly variable, with a prevalence of fibers and fragments (secondary MPs) and pellet shape (primary MPs) in marine environments (Kutralam-Muniasamy et al., 2020). For example, pellets were more commonly found on the Caribbean coast and beaches of Colombia (Acosta-Coley and Olivero-Verbel, 2015; Acosta-Coley et al., 2019a, 2019b; Garcés-Ordóñez et al., 2019; Rangel-Buitrago et al., 2019b), while fibers were predominantly found in the rest of the beaches, coasts and estuaries of the region. Although there is a wide variety of polymers that make up MPs, these studies have also shown that the most common polymers found are polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS), in these aquatic environments (Kutralam-Muniasamy et al., 2020). On the other hand, Lebreton et al. (2017) presented a global model of plastic pollution inputs from rivers into oceans based on waste management, population density, and hydrological information. These authors suggested that in South America, the Magdalena River (Colombia's central waterway), and the Amazon River would be among the most plastic polluted rivers globally. These South American rivers present an annual input of 16,700 tons/year entering the Gulf of Mexico, and 39,900 tons/year going into the Atlantic Ocean. Finally, different ONGs performed a waste census in 813.554 m^2 on coastal areas of the Province of Buenos Aires, Argentina, during 2018. These ONGs reported that more than 80% inorganic solid waste found on these beaches were plastics being the main ones bags, cigarette butts, bottles, nylon remains, and bottle tops (ONG Vida Silvestre, 2019). All this trash is a potential MPs source on these beaches and coastal areas.

On the other hand, nanotechnology has made great technological contributions to science, engineered, industrial, and medicine due to their intrinsic properties (e.g., high specific surfaces, quantum effects) (Cookson and Wang, 2005; Patra and Gouda, 2013; Yetisen et al., 2016). In particular, nanotechnology is employed in the textile industry to improve the textiles and fibers properties (e.g., conductivity/antistatic, resistance, thermal, UV-protection, self-cleaning). Due to hygiene, health, and well-being concerns have created an increasing demand for antimicrobial textiles in recent years. In particular, metals and metal-oxides nanoparticles are among the nanotechnology most employed in the textile industry due to antimicrobial properties (Yetisen et al., 2016). According to antimicrobial activity mechanics of antimicrobial textiles, they can be divided into biostatic (inhibit the growth of microorganism) and biocidal (kill the microorganism). However, biostatic textiles are most employed due to preserving the natural bacterial flora of the skin (Bonaldi, 2018). Nanoparticles from commercial textiles can be released during washing and/or abrasive exposure, causing their accumulation in water bodies and soil (Mazari et al., 2020). Focusing on South America, Argentina, Brazil, and Chile due to their scientific capacity has been encouraging and developing nanotechnology and its incorporation into industrial processes in the last years (Foladori et al., 2013). Actually, a variety of nanoparticles are available in different commercial products in the South American market such as clothes, sunscreen, and disinfectants, among others.

Overall, this work provides a comprehensive reflection and perspectives over how the COVID-19 pandemic can aggravate plastic pollution on beaches and coastal environments in the next few years in South America and, consequently, increase the damage to some marine species. Moreover, the pandemic's potential impact on waste management systems and future research directions to improve the integrated coastal management strategies are discussed.

2. Methods

A detailed search was conducted in this article, including governmental and NGO websites, comprising as much of the latest research articles available on PMs and COVID-19 in South America as possible.The examination was performed utilizing search engines such as Sciencedirect, Google Scholar, PubMed, SciELO, Scopus, and Springer. The keywords or terms used for the search were: *personal protective equipment (PPE), SARS-CoV-2 virus infection, COVID-19 pandemic in South American countries, public policies of curfew and social distancing, plastic pollution, waste management on beaches and coasts of South America, plastic waste in South America, engineered nanoparticles, and antiviral polymeric textiles*. For these keywords Boolean operators such as "AND"/"OR" were used in the identification of the scientific literature. However, searches concerning information of Municipal Solid Waste management in some South American countries were complex due to the limited information available.

On the other hand, there were included photographic records of COVID-19 related-waste made by the authors of this article, researchers or people as part of the citizen science, who work in collaboration with the authors at some beaches or coastal areas of South America.

3. Plastic production and waste management during the pandemic in South America

Polymers are the most widely employed materials in the hospital-medical industry due to lighter weight, better biocompatibility, and lower cost. In particular, the PPE is manufactured with polymers and polymer fibers such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyurethane (PUR), polyacrylonitrile (PAN), polystyrene (PS), polycarbonate (PC), among others (Fadare and Okoffo, 2020; Prata et al., 2020). The use of PPE, especially face mask, face protectors, and N95 medical mask has become an invaluable and critical resource to prevent and decrease pandemic spread around the world. There are different types of face masks available according to their use during the pandemic such as medical, filtering facepiece, and non-medical such as cloth masks (Rubio-Romero et al., 2020). In general, medical face mask comprises three layers, an outer one of nonwoven fibers (they are water-resistant), a middle one (melt-blown filter, which is the primary filtering layer of the mask), and an inner layer (soft fibers) (Fadare and Okoffo, 2020). Prata et al. (2020) estimated 129 billion face masks and 65 billion gloves are utilized worldwide. This situation has led to a shortage of PPE, (especially medical masks) in many European and American countries. For this reason, some countries such as the USA and the Republic of Ireland (under emergency crises by COVID-19 pandemic) have applied strategies to implement reprocessing technologies and effective decontamination of disposable PPE using ultraviolet light (UV), ethylene oxide (EO), hydrogen peroxide vapor (VH_2O_2) and chemicals liquid disinfectants among others (Ilyas et al., 2020; Rowan and Laffey, 2020). Moreover, It is worth mentioning that in order to achieve a good management and disinfection technology of the COVID-19 medical waste from hospital healthcare, and household waste from positive patients in mandatory quarantine, it must be taken into account the cost and maintenance of the adaptation of the MSW, as well as the volume, and type of waste generated (Ilyas et al., 2020; Wang et al., 2020).

Focusing on South American countries, during the pandemic, there was a shortage of PPE and alcohol gel as well as the raw materials for their manufacture. This shortage of PPE has led health workers and the South American population to dedicate themselves to making all kinds of improvised protective suits manufactured with garbage bags, and face masks elaborated with synthetic textiles (cloth mask), or paper. In particular, cloth masks are washable and cost-effective because they are manufactured with commercial synthetic textiles such as chiffon, spandex, cotton quilts, flannel synthetic silk, among others (Konda et al., 2020; Shruti et al., 2020). These synthetic textiles are manufactured with polymers or polymers-natural fibers mixes. The most employed polymers in the manufacture of these synthetic textiles are polyester, nylon, or polyether-polyurea copolymer (Konda et al., 2020; Shruti et al., 2020). Thus, these types of textiles may also contribute to the MPs pool as fibers, which are released during domestic washing into wastewaters and later reach wastewater treatment plants (WWTP) (Kutralam-Muniasamy et al., 2020). The consequent release of these textile fibers into the oceans can be caused by laundry machines which fail in the retention of them as well as inefficient WWTPs in many South American countries.

In April 2020, the use of face masks for everyone in public spaces was mandatory in most of these countries. In this way, for example, the Colombian plastic industry estimated an increase in the monthly manufacture of face masks (from 2 to 8–10 million), of N95 medical masks (from 60,000 to 100,000), and it imported over 2 million of gloves (Acoplasticos, 2020). Likewise, the principal Latin American pulp and paper manufacturer reported the production of 18,5 million masks/month in Brazil, Chile, Perú, and Mexico (Groupenp, 2020). For example, companies like Softys, installed the production of face masks in South American countries such as Argentina, Brazil, Peru, and Chile, where it estimates a monthly production of 20 million (SOFTYS, 2020). Besides, Urban and Nakada (2020) evaluated the impact of the COVID-19 pandemic on Brazil's environment and solid waste management system. These authors reported that more than 85 million face masks might be daily disposed in Brazil. This strong demand in production and/or importation and the excessive use can lead to the mismanagement of medical waste by medical personnel and citizens due to the global COVID-19 pandemic. Moreover, the lack of knowledge about the type of domestic waste generated and its deficient classification by the people at home also contribute to the increased plastic pollution during the pandemic. This situation has alerted the scientific community due to the increase in plastic pollution in aquatic environments (Akber Abbasi et al., 2020; Aragaw, 2020; Fadare and Okoffo, 2020; Silva et al., 2020a, 2020b; Prata et al., 2020; Shruti et al., 2020; Vanapalli et al., 2020). Recent studies have already informed the potential danger of face mask fragmentation into MPs (Akber Abbasi et al., 2020; Aragaw, 2020; Fadare and Okoffo, 2020; Silva et al., 2020b; Shruti et al., 2020). In addition to this plastic PPE waste, the pandemic has increased the use of other disposable plastics such as PP, HDPE, LDPE, PET (Vanapalli et al., 2020), being also potential sources of MPs. Unlike medical waste, which is generally treated as hazardous waste through incineration and autoclaving (Decree 06/2009; ICEX, 2018; CAITPA, 2020; MinSalud, 2020; National COEa, 2020); the increase in plastics and masks used by citizens is at the mercy of household waste management. On many South American coasts, it is increasingly common to find discarded chin straps and other personal protection items such as face masks or gloves, which are potential sources of MPs. Besides, as expected, in rivers and other tributaries which discharge in coastal environments like estuaries and beaches, the amount of these protective elements is very significant (Fig. 1). Also, the ONG Argonauta Institute for Coastal and Marine Conservation reported the death of one Magellanic penguin (*Spheniscus magellanicus*) by the ingestion of an N95 face mask on the north coast (Juquehy beach) of the State of São Paulo, Brazil (ONG Argonauta, 2020). This species of penguin migrates every year from Argentine Patagonia in search of food, but some get lost from their group and end up on Brazilian beaches (ONG Argonauta, 2020). Moreover, cloth masks also represent a danger to marine organisms because they can get caught with the straps. In this sense, there are currently several campaigns that ask people to cut the straps from the masks to avoid animals getting trapped in them. Thus, in the medium or long term many of these PPE, will end as MPs like authors recently mentioned in their works (e.g. Aragaw, 2020; Fadare and Okoffo, 2020; Silva et al., 2020b; Prata et al., 2020; Shruti et al., 2020).

Even if South American countries have presented an advance in the implementation of Municipal Solid Waste (MSW) management, this system is not environmentally sustainable in many cities of these developing countries because of deficits and deficiency in final waste disposition (see, Table 1) (Kaza et al., 2018; Padilla and Trujillo, 2018; UNEP, 2018a). In particular, these shortcomings in the MSW system have been accentuated during the COVID-19 pandemic due to lack of preparedness in managing the increased volume of medical waste, and essential services such as waste collection (UNSDG, 2020). In this way, Table 2 presents a summary of South American Solid waste management systems' deficiencies (before and during the pandemic) and future recommendations to improve the quality of these systems. Some of these recommendations are based on international-best evidence previously mentioned by other works (e.g. Silva et al., 2020a, 2020b; Prata et al., 2020; Sharma et al., 2020; Vanapalli et al., 2020). Before COVID-19 pandemic, Latin America and the Caribbean had the lowest percentage (4.5%) of recycling in comparison to other regions such as Europe and the USA (Kaza et al., 2018). Moreover, UN (UNEP, 2018b) Environmental Program warned that in Latin America and the Caribbean, a third of urban waste ends up in open dumps. These practices are soil, water and air pollutants and it is still a challenge to eradicate them (Kaza et al., 2018; UNEP, 2018a). On the other hand, waste management took a back seat due to the pandemic, bringing about a drastic decrease in the recycling percentage, especially in the first few months where most activities were restricted by curfews or quarantines. (Red Lacre, 2020). For example, in Argentina, the plants for the municipal separation of waste (NGOs and Cooperatives) are closed, and the activity of informal recyclable waste collectors was paralyzed during the first months (May 2020), as it also happened in Ecuador, and Colombia (UN/CCCB-CCRE, 2020; National COEb, 2020; MinJusticia, 2020), Chile until April (MMA Chile, 2020) and Perú until July (Gob.Pe, 2020). In some Brazilian cities recycling programs were suspended however, in the city of São Paulo (the largest city of South America) they were not discontinued (ABES, 2020; Urban and Nakada, 2020). Considering that recycling is fundamental to achieve the objectives of sustainable development, the activity of informal recyclers is substantial, since, in Latin America, they are the largest contributors to waste recycling (CODS, 2020). Therefore, it is essential to move towards waste management focused on recycling, in an inclusive way to prevent pollution and protect resources (Varotto and Spagnolli, 2017; Ma et al., 2019). Waste collectors must have formal integration and recognition, with insurance coverage and protective logistics.

In addition to the growing increase in PPE and disposable plastics, the pandemic has generated innovations and significant technological advances to avoid contagion (Hiragond et al., 2018; Chua et al., 2020; MinCyT, 2020). The use of Ag and Cu nanoparticles with active functionalities to combat pathogens and guarantee asepsis is an example of this (Hiragond et al., 2018; Chua et al., 2020). South American countries such as Argentina and Chile have marketed face masks with bactericidal, fungicidal, and antiviral properties (MinCyT, 2020; EFE, 2020) as well as the use of spray and gels with Cu nanoparticles (Inteco Chile, 2020). This technology is being utilized to disinfect hospitals and nursing homes. It is known that synthetic or engineered nanoparticles have been denominated as emerging contaminants. Engineered nanoparticles (ENPs) are those materials made up of many atoms or molecules bonded with each other, whose size ranges between 1 and 100 nm (Wang et al., 2019). ENPs have unique fundamental properties (electrical, optical, chemical, and physical) and biological activity that may differ significantly from ion and bulk materials (Simoncic and Tomsic, 2010; Malakar and Snow, 2020). The properties of ENPs are mainly determined by their size-shape, composition, crystallinity, and structure (Simoncic and Tomsic, 2010; Malakar and Snow, 2020). The ENPs can range from simple metal oxides to complex core-shell NPs (Delay and Frimmel, 2012).

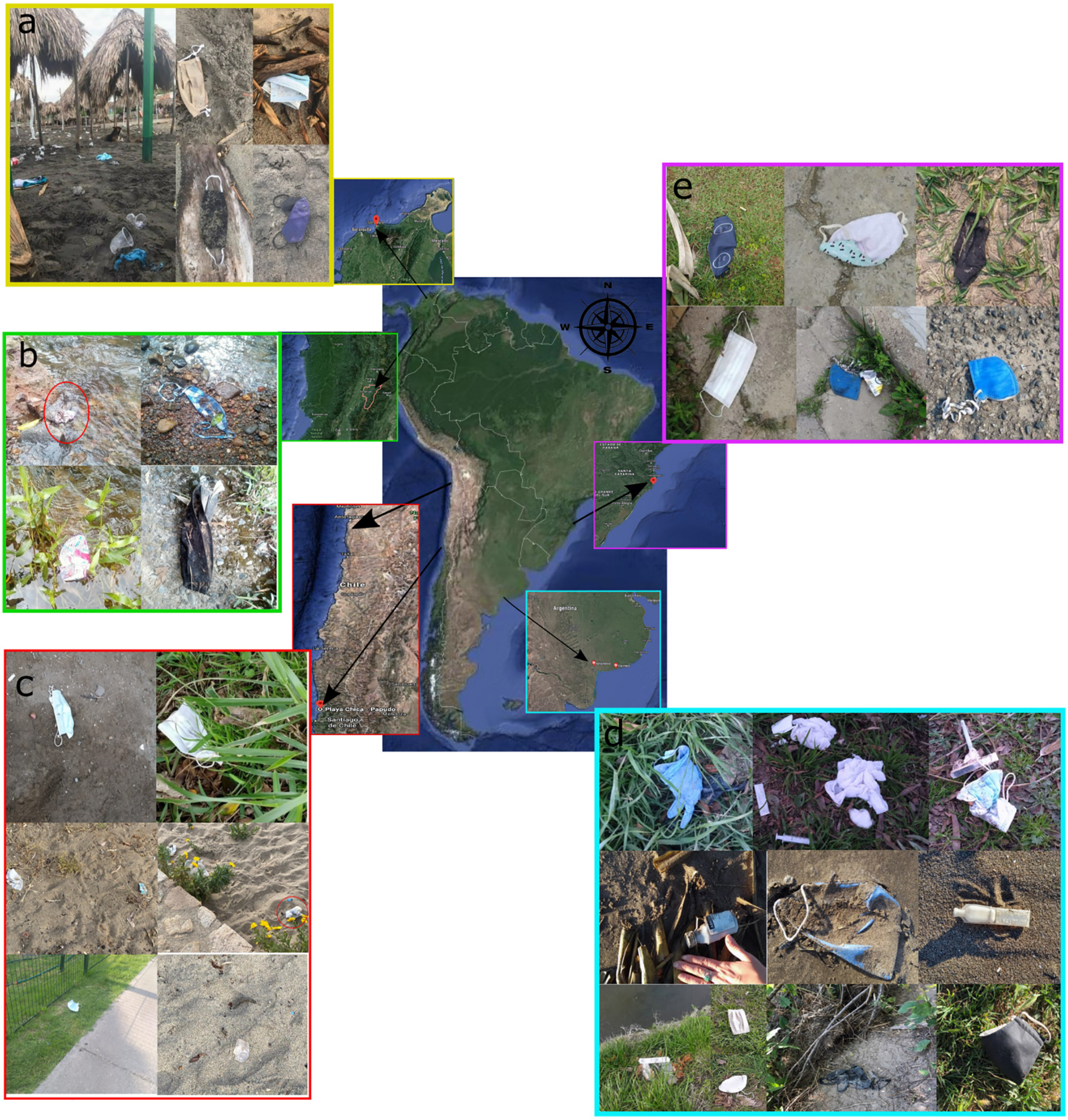

Fig. 1. Waste related to the Covid-19 pandemic: (a) disposable medical face masks found on beaches at Colombia Port, Santa Martha, Colombia. (b) cloth masks found in the water intakes of Roble River aqueduct (Circasia, Quindío), Colombia. (c) disposable medical face masks, and wet wipes found on Amarilla beach in Antofagasta, and Papudo beaches in Santiago de Chile, Chile. (d) disposable medical face masks, medical waste containers, gloves, and face protector found on the Claromecó beaches, Bahía Blanca city and their natural reserve, Buenos Aires, Argentina, and (e) disposable medical face masks and cloth mask found in the city of Imbituba, Santa Catarina in Brazil (all less than 700 m away the coast).

Several studies have reported the release of ENPs in aquatic environments from commercial products and their long-term effect as a potential pollutant in these water sources and their extreme danger for aquatic organisms (Peters et al., 2018; Malakar et al., 2019). Depending on nanoparticles' unique size and properties, their toxicity on organisms may be different from the bulk material (Malakar and Snow, 2020). Recently some organizations such as the Center for Biological Diversity (CBD), and Beyond Pesticides (formerly National Coalition Against the Misuse of Pesticides) from the USA have informed their concern on the indiscriminate use of textiles and other materials infused with toxic antimicrobial substances (with AgENPs and CuENPs) for manufacturing face masks and other commercial products (Beyond Pesticides, 2020; CBD, 2020). The release into waterways of nanofibers with ENPs from antiviral face masks during wash cycles in washing machines and the indiscriminate use of commercial disinfectant products with ENPs could potentiate the negative impact of MPs pollution on some marine species. In this way, recent studies have been performed over the molecular interactions between the ENPs and MPs/PNPs (Li et al., 2019) and their combined toxicity on aquatic organisms such as microalgae (Davarpanah and Guilhermino, 2019; Zhu et al., 2020), planktonic crustacean (Pacheco et al., 2018) and fish (Ferreira et al., 2016; Estrela et al., 2021). Both contaminants present similar sources such as industrial, personal care and domestic products (Bakaraki Turan et al., 2019; Gunasekaran et al., 2020). Likewise, similar routes in sewage or effluents from treatment plants, landfills, and surface runoff could interact and coexist with other pollutants (Gunasekaran et al., 2020).

Li et al. (2019) investigated the interaction between the PE, PP, and PS microplastics and AgENPs in aquatic environments. These authors informed that PS microplastics could act as vectors of the AgENPs in water due to the fact that these nanoparticles can be captured on the surface of

Table 1
Relative values of final disposition waste treatment in South American countries, (adapted from Margallo et al. (2019) and the Panamerican Health Organization).

Countries	Sanitary landfill	Controlled landfill	Open dumps	Other treatments
Argentina	64.7	9.9	24.6	0.8
Brazil	55	20.2	24.5	0.3
Chile	81.05	13.8	4.0	0.7
Uruguay	3.8	68.2	18.1	9.8
Paraguay	36.4	40.2	23.4	0
Bolivia	44.7	16.4	10.6	28.2
Perú	43.5	10.6	45.3	0.6
Venezuela	12.9	40.9	45.6	0.5
Colombia	81.8	4.1	12.5	1.5
Ecuador	30.2	46.3	20.5	2.9
Guayana	–	–	–	–
French Guayana	–	–	–	–
Surinam	–	–	–	–

the MPs. On the other hand, Oliveira et al., 2018 investigated the river dynamic, the formation of NPs (Fe-NPs and TiO_2-NPs) and their association with Potential Hazardous Elements (PHEs) present in suspended sediments (SS) of the Magdalena River, in Colombia. These authors informed that these nanoparticles might absorb and concentrate PHEs (e.g. Cr, As, Hg, Pb, Cd) as well as change the geomobility and the ecotoxicity of PHEs in the SS. Still, more studies are needed to fully understand these interactions, especially in natural settings. Ecotoxicological studies on the impact of ENPs in South American aquatic ecosystems and species must continue to be developed. Characteristics of ENPs such as size, shape, chemical composition, surface structure, charge, solubility, and the aggregation state seem to be very important for their environmental impact and all of them must be properly judged (Navarro et al., 2008; Radetic and Saponjic, 2018). However it should be started to monitor them since very little information is available for South American countries and represent potential damages.

Therefore, it is necessary to invest in technology and infrastructure to research and monitor ENPs pollution in different aquatic environments, developing standardized methods that detect, quantify, and characterize ENPs under environmental conditions (Radetic and Saponjic, 2018). Finally, nanotechnology's development using renewable and biodegradable materials that have less environmental impact and shorter life cycles.

4. Coastal management in the new reality

Since 1970, MPs pollution (previously named as plastic particles) in coastal and ocean waters has been recognized as part of the plastic contamination problem, although it was less important than other pollutants, such as oil residues (Moore, 2008; Kramm and Volker, 2018). Since then, the problem of MPs has grown, not only due to the uncertainty of its negative effects, but also to a conflict of opinions on how to tackle the problem (Kramm and Volker, 2018). The current situation in the face of the COVID-19 pandemic, leads us to rethink how to protect coastal and marine areas from the pollution of MPs, one of the most important environmental challenges of our time that can be aggravated by the pandemic also causing severe socio-economic consequences for human beings (Peters et al., 2018; Tischer et al., 2013). Many of the environmental goods and services provided by the coasts are the basis of important activities such as aquaculture, fishing, port development, industry, tourism, etc. (Lemay, 1998). Among these activities, tourism in the coastal areas of many countries in South America plays a significant role directly and indirectly contributing to plastic pollution as well as pressure on natural systems (Navarro, 2019). However, this is one of the activities that has been most affected by the current pandemic, which according to World Tourism Organization (UNWTO), the decrease since the arrival of COVID-19 is around 50% in South America, with the consequent danger of job losses for those who are related to such activities (UNWTO, 2020a). Although this closure or reduction of tourist activities resulted in cleaner water and air, reduced noise pollution and less waste (Zambrano-Monserrate et al., 2020), these will not be long-term effects. 80% of global tourism occurs in coastal areas (UNWTO, 2020b), so the pollution generated by this type of activity quickly reaches beaches and seas. Mass tourism promotes an occupation of the coastal area, capable of generating a high impact, transforming or degrading landscapes and ecosystems. This is counterproductive to its own development weakening it, if it is not adequately managed (Lemay, 1998; Boscarol et al., 2016).

The measures taken to reactivate tourism in the face of the new reality left by the pandemic should not be less important than the measures to prevent contamination. The widespread use of face masks and single-use plastic are waste products generated by the pandemic, and they have become the new environmental problem (Hyde, 2020; Ormaza-González and Castro-Rodas, 2020). Currently, many countries in South America are part of the UN Environment Clean Seas campaign, which seeks to reduce the volume of disposable plastics, eliminate the use of plastics, and protect coastal ecosystems (UNEP, 2018c). Among the South American countries that are part of this campaign are Argentina, Brazil, Chile, Colombia, Ecuador, Guyana, Peru, and Uruguay (UN, 2018). Within this campaign, many of the initiatives are based on banning single-use plastics (bags, straws, disposable tableware, etc.), especially in coastal and touristic cities (UN, 2018). For instance, Mar del Plata, Pinamar, Buenos Aires in Argentina (Decree N° 853/19; Ordinance 4102/12); Rio de Janeiro in Brazil (Law N° 8006/18); Perú (Ministerial Resolution N°166). UNWTO (2020a, 2020b) mentioned that single-use plastics should not be considered as a measure against contagion in the current pandemic and that the priority should be the disinfection and social distance. The measures, which prohibit certain single plastic items, must advance progressively throughout the entire territory. The lack of these regulations in other cities can affect lake waters and rivers that flow into the sea.

In light of the remarkable changes in the environment under this pandemic context, we now have a unique opportunity to change previous bad habits in terms of natural resources, use and waste management. Also, emphasis should be placed on strengthening responsible and more sustainable tourism as a strategic axis for managing coastal environments (Boscarol et al., 2016). The participation of various sectors must be active: i) the government/public sector, promoting regulations to leave single-use plastic behind, ii) civil societies and scientific/technical universities, researching the state of plastic pollution, working on the creation of new biodegradable materials, and educating citizens for best practices, and iii) the business sector, promoting services and activities dedicated to ecotourism within a sustainable perspective. Besides, cleaning and sanitation procedures, communication with tourists, and reducing the plastic footprint are important axes to be taken into account by the tourism sector (UNEP, 2020a).

Furthermore, proper waste management is of utmost importance for cities and coastal towns, since their growth rate in most all Latin American countries is much higher than in inland regions. This supposes a constant pressure on the coastal spaces, compromising their health (Lemay, 1998). Due to poor waste management, gloves, disinfectant bottles, masks and other plastic products resulting from the pandemic, have been found in the natural coastal environments of the main touristic destinations (The Guardian, 2020).

Part of coastal management is to prevent and avoid pollution (Sharma et al., 2020), and in order to address MPs pollution, it must be first considered a socio-ecological problem. MPs not only affect the ecosystems where they accumulate, but they also have a political, social and economic impact (Kramm and Volker, 2018). This is why strategies must go beyond keeping beaches and surrounding coastal areas clean with citizen integration, education in sustainable consumption, different ways of recycling and betting on reduction. The role of citizens as responsible and participatory consumers is vital to enable the change towards more sustainable and healthy policies (Rojo-Nieto and Montoto, 2017). The political leadership must guarantee an investment in waste

Table 2
Deficiencies in South American waste management systems (before and during the pandemic), recommendations and probable solutions.

Solid Waste Management in South America		
Before pandemic	During the pandemic	Potential Solutions
Poor infrastructure and facilities for waste disposal and recycling in some cities and towns.	The facilities were partially or totally closed during the first months due to the COVID-19 public curfew policies.	- Investing in infrastructure and sorting plants will reduce the use of raw materials and waste going to landfills and create new job opportunities. - Developing sustainable technologies to convert waste into energy (composting, thermal gasification, treatment biological mechanic, incineration). - Focusing on developing new and sustainable technologies to recycle mixed or complex plastic into pristine polymers.
Incomplete solid waste collection services in some rural and urban areas.	Solid waste collection services were partially suspended in some rural and urban areas, and collection frequency decreased in others.	- Increasing the number of trucks and/or the frequency of recollection and with differentiation in the type of waste. If this is not possible, drop-off sites can be used for the collection of paper, cardboard, glass and light packaging, being this a good solution widely used by European countries.
Low percentage of waste recycling	The tasks of formal and informal recyclers and recycling plants were hampered by the partial or total closure. Fear of contagion from recyclers due to lack of PPE during their working hours.	- Achieving cooperation between formal and informal collectors and recyclers. It is crucial to formally integrate informal waste pickers and provide them with the necessary insurance coverage and PPE to ensure safe work. Including recyclers will increase the number of recycled materials. - Offering funds for the design of new eco-friendly bio-plastics with low or null environmental impact as well as for the development and implementation of circular technologies. - Regulating the use of multilayer plastic containers and products that are not economically feasible to recycle
Illegal open dumpsters, landfill, and burning	The situation remains as the pandemic increases or worsens	- Eliminating open dumps, converting controlled landfills with energy recovery, if possible. - Investing on sorting plants to avoid recyclable materials ending up in landfills. - Treating with incineration for energy recovery
Scarce and outdated statistical data about the amount and composition of waste generated in each country	The amount of waste during the pandemic increased or decreased according to each country, also its composition changed.	- Promoting studies for the characterization of waste. This is essential to develop adequate waste management strategies. The proportion of the different waste fractions will determine the waste collection protocols and waste treatment technologies to be used. - Designing a system based on information from local governments and consolidating it at national level.
Small advances and changes in solid waste management and recycling laws and policies	Deficiencies in the management system were exacerbated, especially in countries with poor infrastructure, sustainable technologies, and policies.	- Advancing in the legislation and environmental policies that define strategies, institutional support, and regulatory frameworks. - Creating State policies to favor the purchase of recycled products. - Promoting planning and development policies of solid waste management according to fastest-growing and most developed cities. - Encouraging the study for the improvement and integration of waste management systems, including different combinations of treatments throughout their stages (example combination of recycling, composting and landfilling). - Articulating waste management policies with environmental education.
Poor recycling culture in citizens Inadequate separation, and classification of solid waste at homes	The rate of waste separation for recycling decreased due to the cessation of differentiated collection. Increase in the consumption of disposable products, especially plastics. Ignorance about protocols for medical waste generated at home	- Encouraging domestic recycling and promoting a cultural recycling environment. - Providing uninterrupted recycling programs over time, as well as raising awareness about the consequences of plastic pollution. - Campaigning for the disposal of PPE, such as masks and gloves in sealed garbage bags, can increase public awareness of the safety sanitation workers.
Poor monitoring programs of plastic pollution	Poor to null monitoring programs of plastic pollution in some countries	- Boosting the active participation of governmental, public, and business sectors to participate in monitoring programs. - Prioritizing plastic prevention and overall reduction. - Fomenting financing, international cooperation as well as sharing ideas for monitoring programs and technology since pollution has a global

Table 2 (*continued*)

Solid Waste Management in South America		
Before pandemic	During the pandemic	Potential Solutions
		impact.
Despite the existing legislation in each country, difficulties persist in the management of hospital waste	Infectious hospital waste increase. Collection systems exceed Waste treatments: Incineration, sterilization and final disposal in landfills. The capacity constraints of in-situ incinerators and central treatment facilities result in illegal dumping of waste into suburban areas, streams, marshlands, etc., raising public health concerns.	- Adopting measures to improve the comprehensive management of hospital waste. - Applying new technologies such as autoclaving, gas sterilization, chemical disinfection, microwave treatment, irradiation and thermal inactivation. - Burying collected waste in a close pit with a clay or geo-synthetic lining at the bottom should be practiced during emergencies (like COVID-19) for safe disposal of hospital waste especially in low-income countries. - Prioritizing the use of automated treatment facilities with minimum operator involvement. - Achieving universal standardization based on type and nature of medical waste. - Training health personnel to avoid excessive waste generation.
Incipient use of nanoparticles for antibacterial purposes	Increased use of textile fibers impregnated with Ag and Cu nanoparticles for manufacturing face masks and commercial products.	- Monitoring water courses systematically, accompanied by derived studies on their possible effects on the coast and marine biota. - Encouraging reuse and teaching about the correct disposal of impregnated textiles once they have reached their useful life.

management systems including recyclers. Policies that allow and facilitate the change of single-use plastics for more ecological products, contemplating laws of responsibility extended to the producer and use standardized labeling are necessary.

Similarly, companies should start looking for environmentally friendly alternative products. In addition, research should play a very important role to guide public policies, by informing about the state of pollution on the coasts, and creating monitoring programs and evaluations (UNEP, 2020b). On the other hand, there is no doubt that nanotechnology has made a significant contribution to different fields such as modern medicine, technology, biotechnology, and engineering, among others disciplines. Due to the diversity of ENPs and their excellent intrinsic properties, they are currently available in different commercial products, technologies, and services from different branches of the economy worldwide. However, there is a growing concern in the scientific community about the indiscriminate use of ENPs, their mismanagement, and poor environmental control (Auffan et al., 2011). As this technology grows, derived studies on its possible effects on coastal and marine biota and bioaccumulation continue to lag. It is not possible to manage without information.

Finally, in all marine and coastal environments, plastic litter threatens the environment, health, and human activities (UNEP, 2020c). Therefore, to address this problem, many approaches at various levels (local, national, regional and international) and with an interrelation between social, economic, political, and environmental dimensions are needed to achieve an effective and integrated management (da Costa et al., 2020). In this way, a summary of recommendations to take into account for coastal management to decrease plastics waste on beaches and coastal areas are presented in Table 3. Finally, it is necessary to rethink when, how and which plastic to use in our daily lives, and if they are indispensable, to allow a real reduction in the long-term. In the short-term governments should improve waste management, incentive citizens as much as possible to reduce, recycle and offer funds for the designing of new plastics with low or null environmental impact. Ecosystems and socioeconomic systems in coastal areas are some of the most threatened by global environmental changes and there is a need to significantly reduce the amount of plastic reaching these environments (de Alencar et al., 2020).

5. Concluding and future directions

The deficiencies in waste management, unreliable recycling habits and low percentage of waste recovery in many South American countries have been accentuated during this pandemic scenario due to the

Table 3
Summary of the most relevant aspects to consider in coastal management to decrease plastic pollution as a cause of the COVID-19 pandemic on South American beaches and coasts.

Sectors	Actions
National governments and the international community	- Intensifying taxes and bans on single-use plastics, working with trade and industry associations, retailers, plastics manufacturers to implement the change as soon as possible. - Eradicating open dumps, in cities near the coast. - Working on laws that implement the principle of Extended Producer Responsibility (EPR). - Promoting economic incentives, supporting projects for recycling single-use items and stimulating the creation of micro-enterprises. - Stimulating research on the development of sustainable technologies to recycle mixture and complex plastics packaging. - Providing educational programs from children. - Working on joint measures with neighboring countries.
Tourist and private industry	- Promoting ecotourism. - Implement UNWTO recommendations on the Global Tourism Plastics Initiative. - Informing tourists about plastic footprint reduction targets. - Following UNEP recommendations on prioritizing disinfection to avoid the spread of the virus, instead of intensifying the indiscriminate use of single-use plastics. - Using local production and stimulating its consumption to help reduce the generation of plastic packaging waste. - Reducing multi-layer packaging and promoting the use of homogeneous plastic packaging materials that are easier to recycle.
Scientific community	- Working on the planning of monitoring and evaluation programs - Identifying possible solutions to guide political sectors. - Offering educational programs and scientific diffusion for the community.
Citizens	- Being responsible consumers by choosing reusable products. - Participating in recycling programs. - Eliminating or reducing as much as possible the use of single-use-plastics. - Advocating for change by means of social pressure on both policy makers and manufacturers to help reduce plastic pollution.

interruption of many human activities. The explosive spread of the virus did not give countries enough time to adapt to this new situation. The lack of preparation of appropriate protocols, poor handling of increased volumes of medical waste and deficiencies in the management of medical and domestic waste collection services could increase in the medium/long term the levels of plastic pollution on beaches, coasts and rivers in South America.

Likewise, the indiscriminate use of new technologies to prevent the SARS-CoV-2 virus infection, such as textile fibers impregnated with Ag and Cu nanoparticles for the manufacture of face masks and commercial products could exacerbate plastic pollution and increase its negative impact on marine biota. Furthermore, there are no studies in South America on the degree of contamination of synthetic nanoparticles in aquatic environments and their real danger to this region's marine fauna.

Microplastic pollution is an invisible enemy with potential adverse effects on marine environment and humans. People, companies and industries, should avoid as much as possible, the use of plastics, and countries should improve sewage discharge treatments, as well as management of bigger plastics. Thus, it is necessary to focus on the critical points of plastic pollution, and work on them not only with political will, but also with citizen collaboration. Deficiencies in management systems must be addressed as a primary objective to achieve sustainable development and to reduce the environmental impact caused by waste on coasts and seas. Also, it is of utmost importance to apply strategies and policies to achieve a more sustainable, responsible and eco-friendly coastal tourism, strengthening the environmental care and respect.

CRediT authorship contribution statement

M. Ardusso: Conceptualization, Funding acquisition, Visualization, Writing – original draft, Writing – review & editing. **A.D. Forero López:** Conceptualization, Funding acquisition, Visualization, Writing – original draft, Writing – review & editing. **N.S. Buzzi:** Visualization, Writing – original draft, Writing – review & editing. **C.V. Spetter:** Visualization, Writing – original draft, Writing – review & editing. **M.D. Fernández Severini:** Conceptualization, Project administration, Funding acquisition, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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